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# MODEL TESTS FOR STOPLOGS SUBJECTED SIMULTANEOUSLY TO OWERFLOW AND UNDERFLOW

Technical Report No. 2

Contents:

**Summary**

For the stoplogs of the WELBEDACHT-DAM in Southafrica investigations about vibration during overflow and underflow were carried out using a scale model 1 to 50.

Test series with stoplog models of different heights and positions gave information about hydrodynamic vertical forces, their fluctuations (vibrations) and frequencies.

As to be expected from similar investigations, vibration forces and frequencies turned out to be fairly remarkable.

## 1. Introduction

At the WELBEDACHT-DAM in Southafrica, stoplogs are provided to be lowered against full headwater in case the radial gates are blocked or damaged.

Respective stoplog steel structures are under construction of the DSD-DILLINGER STAHLBAU GmbH, DILLINGEN, WEST GERMANY. From this contractor, model tests were asked to be carried out at the TECHNICAL UNIVERSITY OF BRUNSWICK in West Germany (TECHNISCHE UNIVERSITÄT BRAUNSCHWEIG).

The investigations shall give information about vibration conditions of the stoplogs simultaneously subjected to overflow and underflow. They were carried out in the hydraulic laboratory of the LEICHTWEISS-INSTITUT at the TECHNICAL UNIVERSITY OF BRUNSWICK.

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## 2. Description of the Model

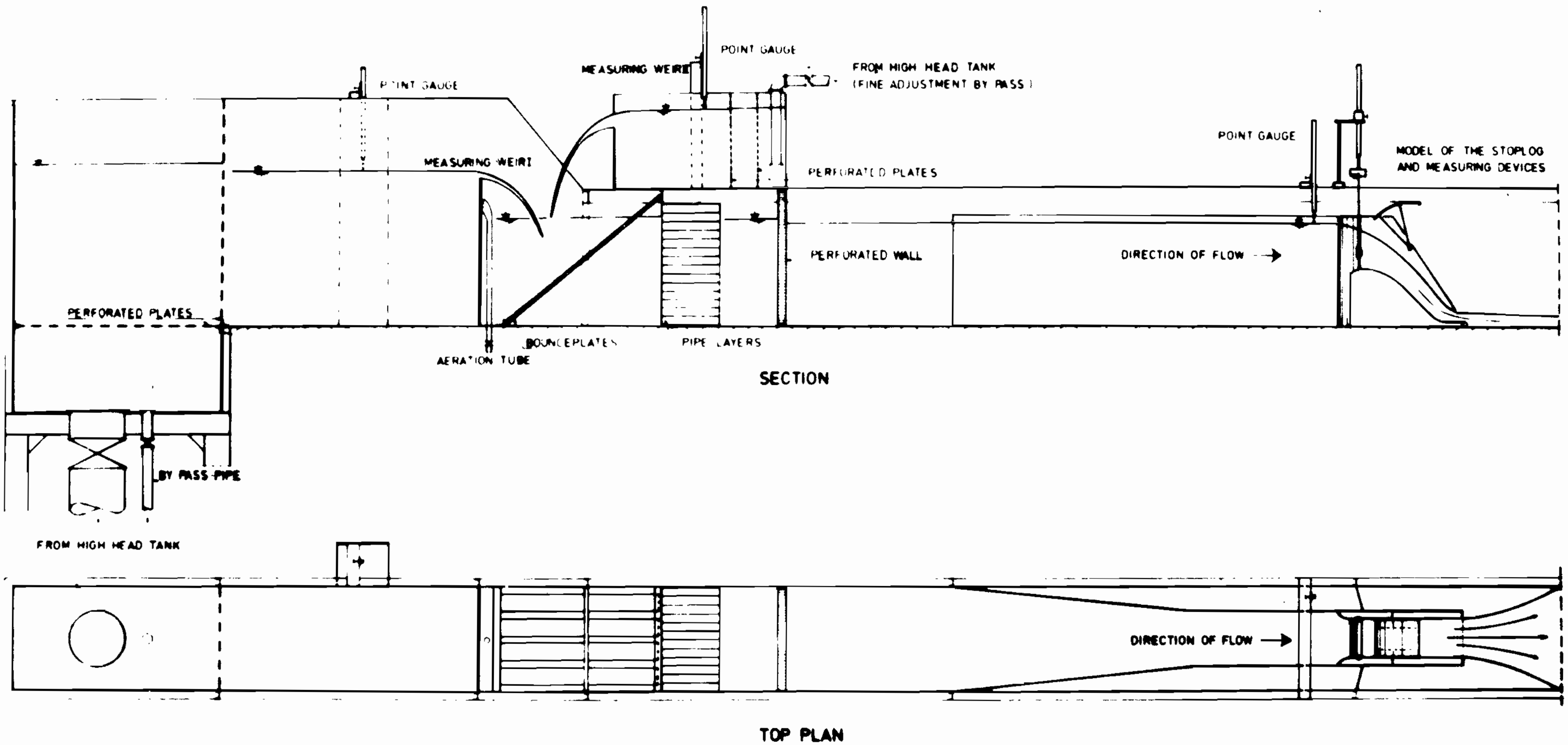
As to be seen from fig. 1 only one opening was reconstructed in the model. Such a simplification may be allowed as the interaction with neighbour gates has no important influence on the origin of the vibrations. In order to simulate the complete conditions for this one opening, the weir crest, the side walls, the slots and the piers till to their axis were reproduced in the model. By this arrangement the contraction of the incoming flow is the same as in the prototype.

With respect to the water supply, the model scale was limited to

$$1 : k = 1 : 50$$

An existing model was used which was constructed just before for the determination of a calibration curve for the WELBEDACHT-DAM.

The model set up and the locations of the measuring devices are shown on fig. 1. For the discharge measurements, two calibrated measuring weirs were used, weir No. I (rectangular type) for rough, weir No. II (triangular type) for fine adjustment of discharge. For an undisturbed water level in the headwater of the gate, a pipe layer system and a perforated wall are damping the water level undulations from the overfalls of the weirs. The constant




SCALE

**FIG. 1**
**MODEL SET UP**

reservoir water level was controlled with a point gauge (about $\pm$ 0.1 mm) in the model.

Because dynamic loads are to be expected, the measurement devices had to be accomodated to these conditions; here a strain gage pick-up was used. A special suspension apparatus was constructed; the stoplog elements are connected with that apparatus by two suspension rods acting on a flexible steel plate on which strain gages are located (see figs. 2 and 3).

By the strain gages, the stress alterations are transferred linearily into such of electrical resistance. In a WHEATSTONE-bridge, these changes of resistance are modulating the voltage output of it; after amplifying these voltages are written on a recorder. Fig. 4 shows the amplifying unit (with WHEATSTONE-bridge, carrier frequency generator and demodulator inclosed) together with the recorder (both fabricates of HOTTINGER-BALDWIN).

With the complete set-up of instruments, frequencies up to 125 cps can be registrated without damping effects.

After FROUDE's law the scales for the parameters of interest are

| | | | | |
|---|---|---|---|---|
| geometry | $1 : k$ | = | 1 : 50 | |
| discharges | $1 : k^{2.5}$ | = | 1 : ~~31250~~ 17670 | nur Schreib-fehler! |
| frequencies | $1 : k^{-0.5}$ | = | 1 : 0.141421 | |
| forces | $1 : k^{3}$ | = | 1 : 125000 | |

For further consideration about scale effects see chapter 5.

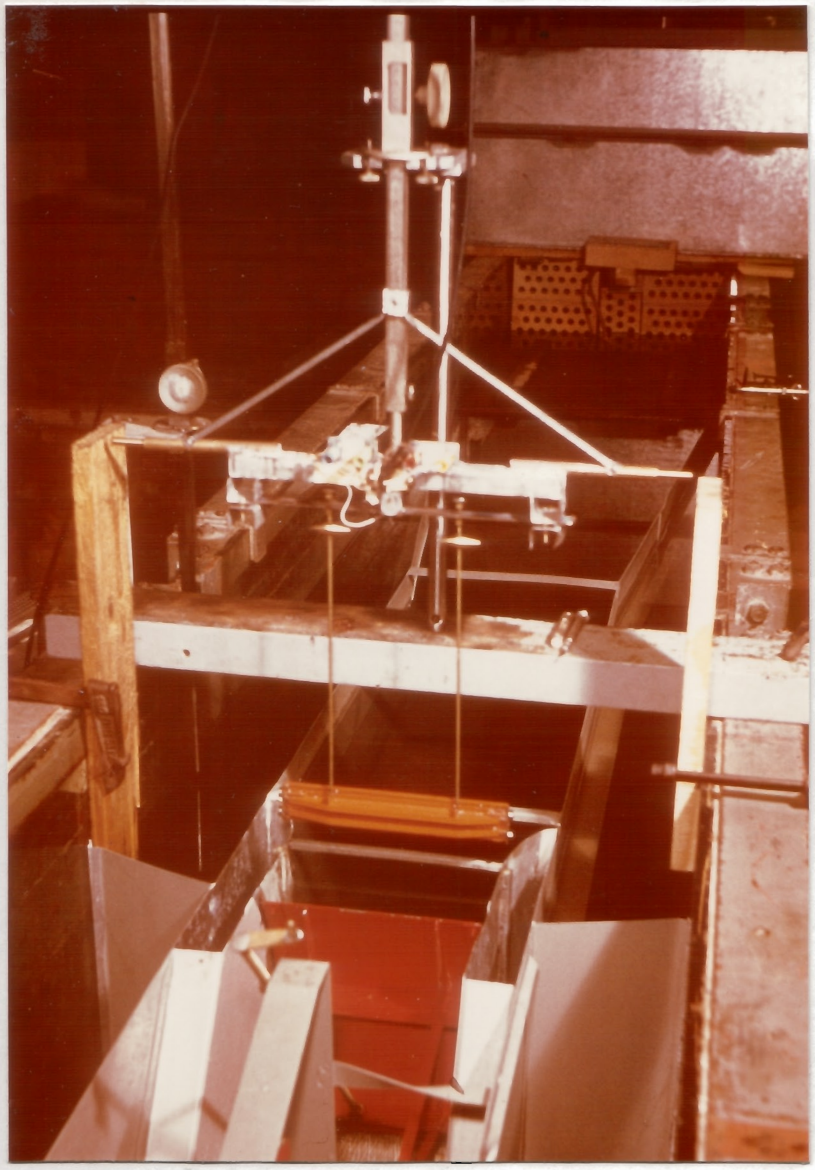


Fig. 2

Downstream View of the Stoplog Model (yellow) and the Suspension Apparatus. Radial Gate (red) Closed.

Fig. 3  Flexible Steel Plate with Strain Gage.

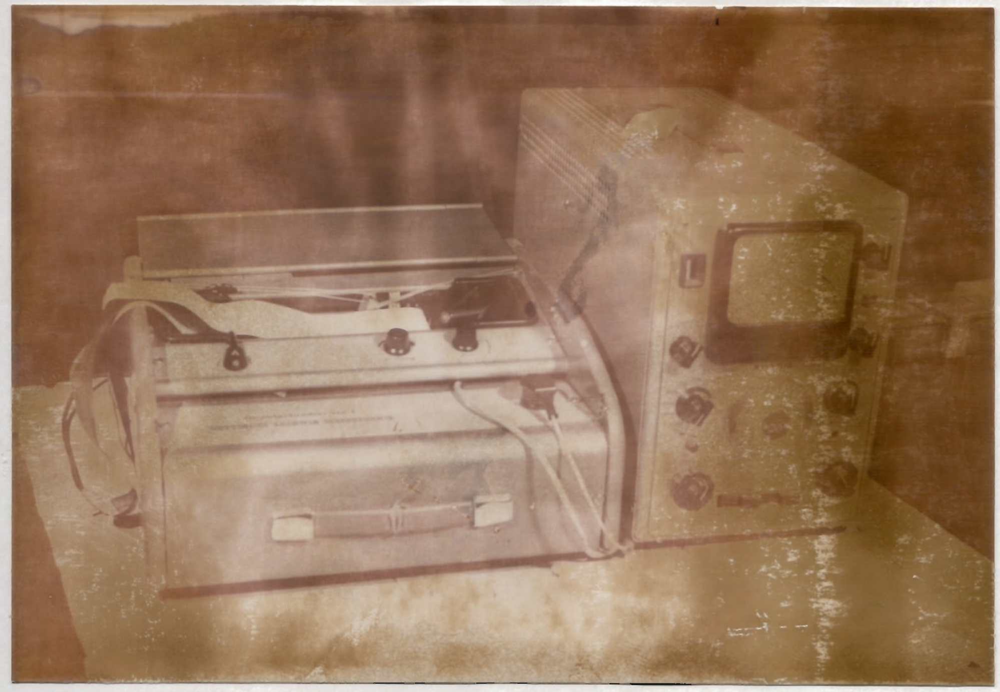


**Fig. 4 Amplifier and Vibration Recorder**

## 3. Results:

The results of the model tests are presented on figs. 7 to 16; all data are scaled up to the prototype after FROUDE's law.

As the test series were carried out with the measuring points having short distances from one another not in all cases, supplementary test series were necessary. On the respective figures there are plotted over the opening rate s:

Hydrodynamic Vertical Force [Mp]

Fluctuating Vertical Force [± Mp]

Vibration Frequencies [c.p.s.]

The measuring points are evaluated from the recorded oscillograms of the vibrations, as well the mean hydrodynamic force as its fluctuations (fig. 16). The (mean) frequencies also were taken from the oscillograms. Whenever there was recognized a sort of beat in the amplitudes of the vibrations the maximum and minimum force amplitudes were plotted in the diagrams (figs. 7 to 16). It was found out generally that maximum force amplitudes appeared together with low frequencies; this was stated also in the investigations by NAUDASCHER [1, 2] .

It shall be noted that in all cases the eigenfrequencies of the testing measuring devices in water and air were much higher than the frequencies of the vibrations observed (relation 5 to 1). Supplementary tests with different eigenfrequencies of the measurement system confirmed that there was no remarkable influence on amplitude and frequency of the vibrations. A strong effect however was found from the friction damping from the rollers in the slots; here ball bearings of highest quality had to be used for the experiments.

With the supplementary tests, changes of the friction conditions also were tested.

Fig. 7 shows the characteristic dependents of behaviour of forces and frequencies during lowering of one beam. Near to the surface the mean hydrodynamic vertical force becomes an uplift force; the fluctuations are low in this range.

With smaller opening rates s, the mean force is directed downwards and remains nearly constant till to the end of the lowering process. In the fluctuations, a strong beat action is to be seen; here the remarkable maximum of fluctuations is at a position where the opening rate s is of the order of magnitude of the height of the beam. On fig. 7 the frequencies have a weak minimum in the medium range of s.

Figures 7 to 10 demonstrate the phenomenon of the decreasing maximum fluctuating vertical force, the more stoplog elements are placed on the sill. Therefore, the most critical conditions are existing for the lowering of the first stoplog. As in fig. 7, the maximum values of the fluctuating vertical forces occur whenever there is left an opening rate s of about the height of the stoplog units even being lowered. A remarkable maximum hydrodynamic downpull action exists for very small opening rates s.

The frequencies possible to be counted out from the oscillograms are in the range of 1 to 1.5 cps (prototype). The changes in frequencies can be explained by the differences in the added mass of water.

Further test series were carried out with two stoplogs coupled forming one element (see fig. 5). Fig. 11 shows that the maximum fluctuating vertical force is not much less than that for only one stoplog (see fig. 7) whereas in fig. 12 this force becomes fairly small because the discharge had decreased due to the 2 stoplog elements placed on the sill.

The fairly undefined region of the hydrodynamic vertical force in fig. 11 is to be explained by the fact that here exists a strong beat in the vibration process.

Furthermore it can be stated that the mean hydrodynamic vertical force acting upward onto two coupled stoplogs in general turned out to be greater than on only one stoplog. This phenomenon can also be seen from fig. 13 where 3 stoplogs are coupled. On the other hand in this test the lowest value for the fluctuating vertical force occurs.

The interpretation of all the behaviour of the vertical force and its fluctuations is highly difficult. The loads are excited on the upper and under surface of the longitudinal beams; at the skinplate, zones of separations are present at these surfaces. Furthermore the eddy generation in the zone of separation behind the complete system together with air pocket effects (see chapter 4) gave some complications more. It is sure however that a control of the forces is possible by fixing the points of separation at the end of the structure. In order to demonstrate this, a test series was carried out with streamline facings at the top and down side of the stoplog unit as to be seen from figs. 6 and 14. It shall be underlined that this form of facings does not give conditions of optimum especially for the mean hydrodynamic force; it can be seen however the high reduction of the fluctuations on fig. 14 compared with fig. 7.

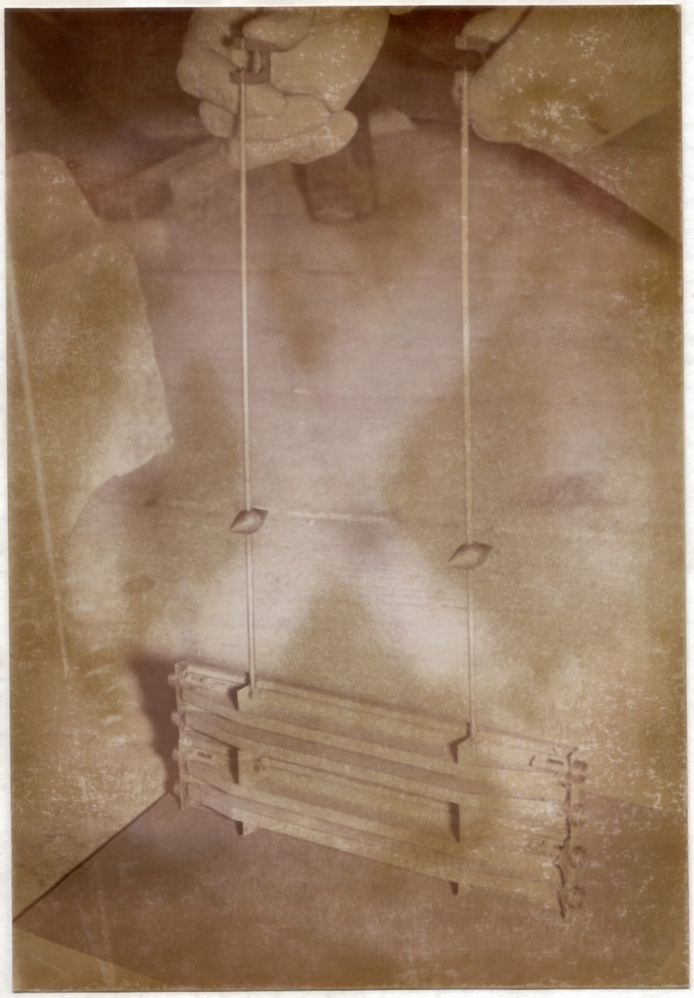


Fig. 5 Two Stoplogs Coupled; Special Formed Elements Attached to the Suspension Rods.

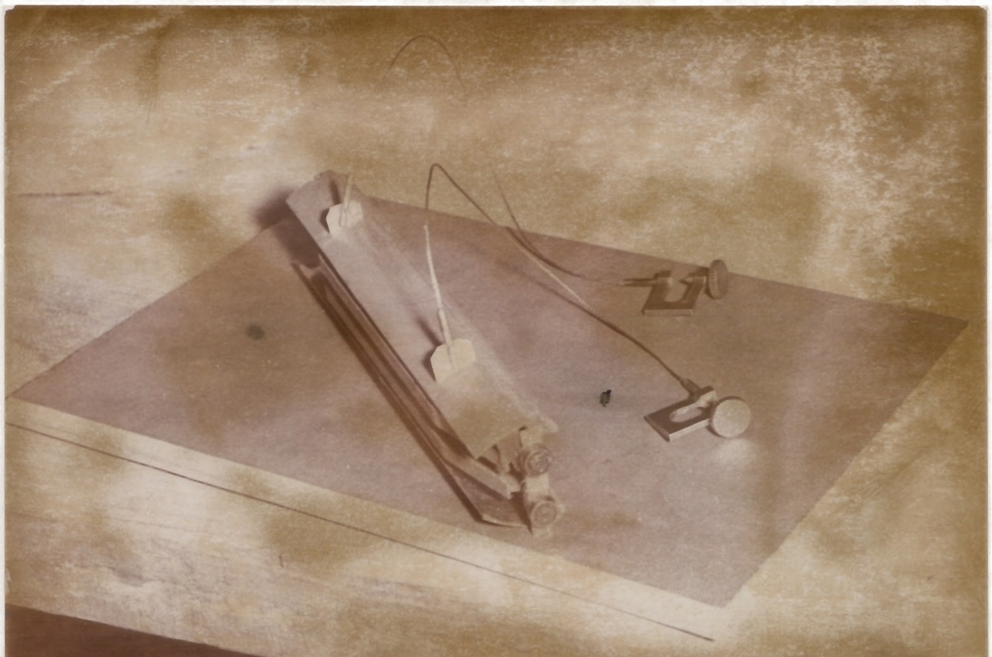


Fig. 6 Modified Stoplog with Wire Rope Suspension.

FIG. 7

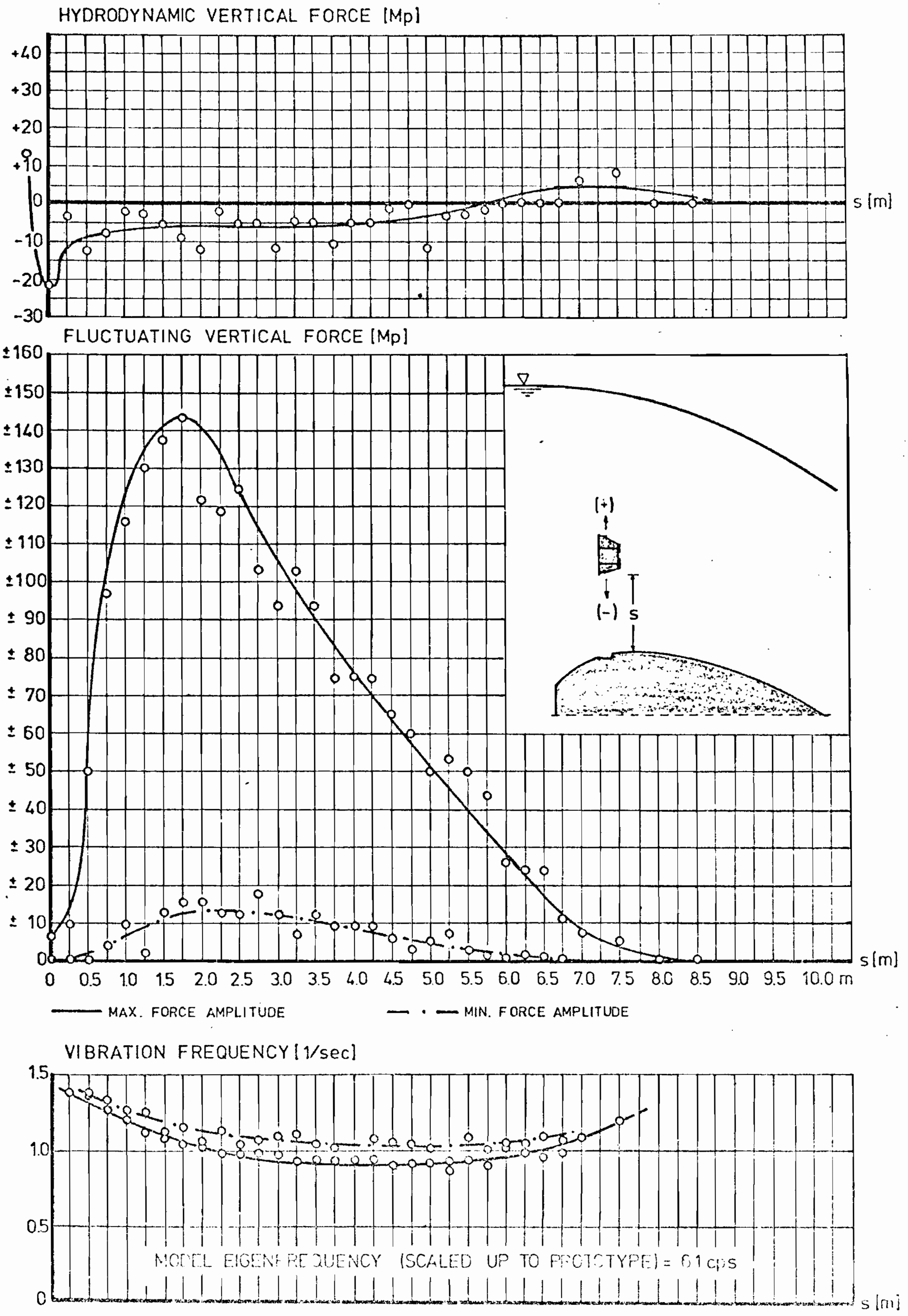

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
MAX. FORCE AMPLITUDE
MIN. FORCE AMPLITUDE
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 6.1 cps
s [m]

FIG. 8

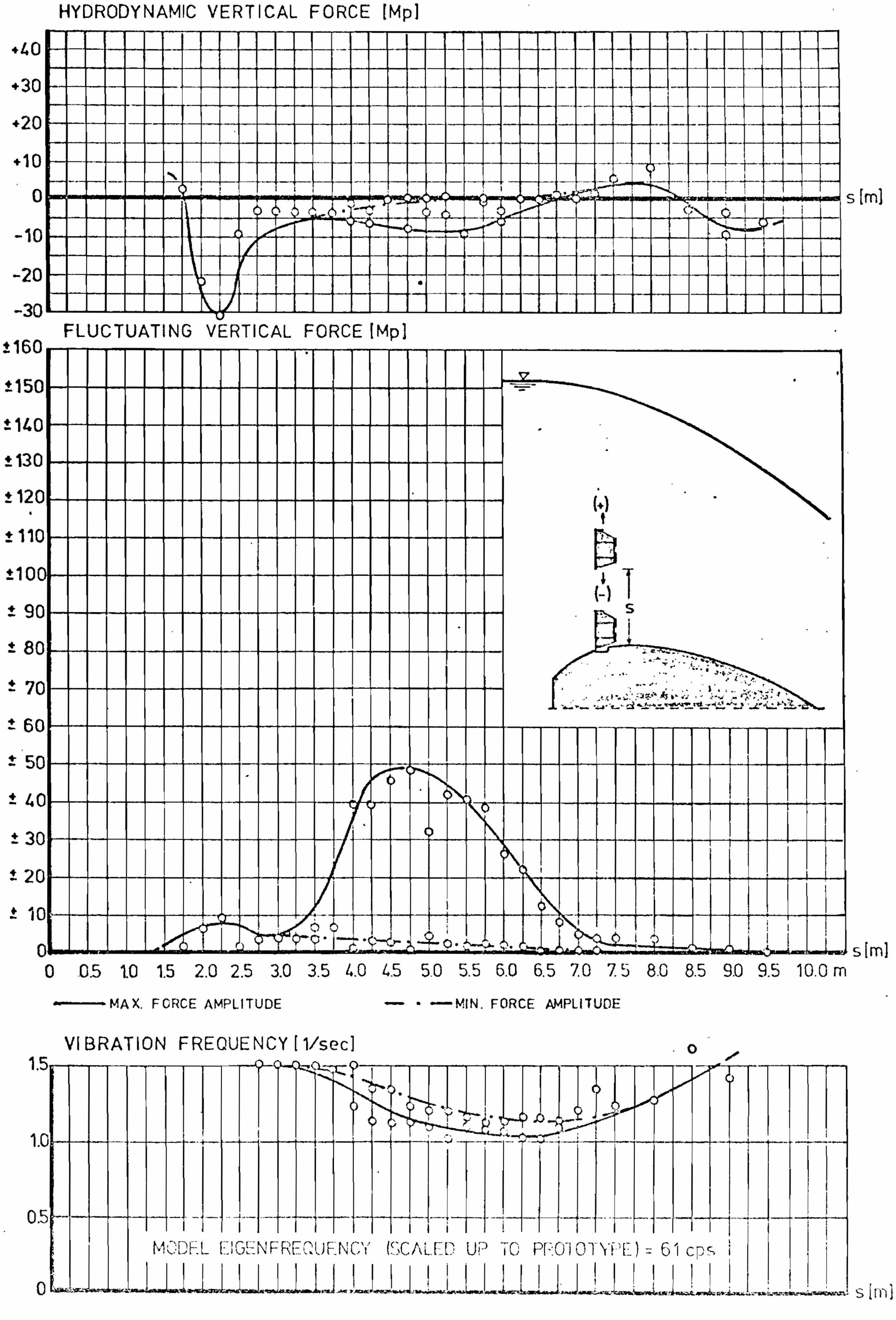

HYDRODYNAMIC VERTICAL FORCE [Mp]
FLUCTUATING VERTICAL FORCE [Mp]
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
(+)
(-)
s
MAX. FORCE AMPLITUDE
MIN. FORCE AMPLITUDE
VIBRATION FREQUENCY [1/sec]
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 61 cps

FIG. 9

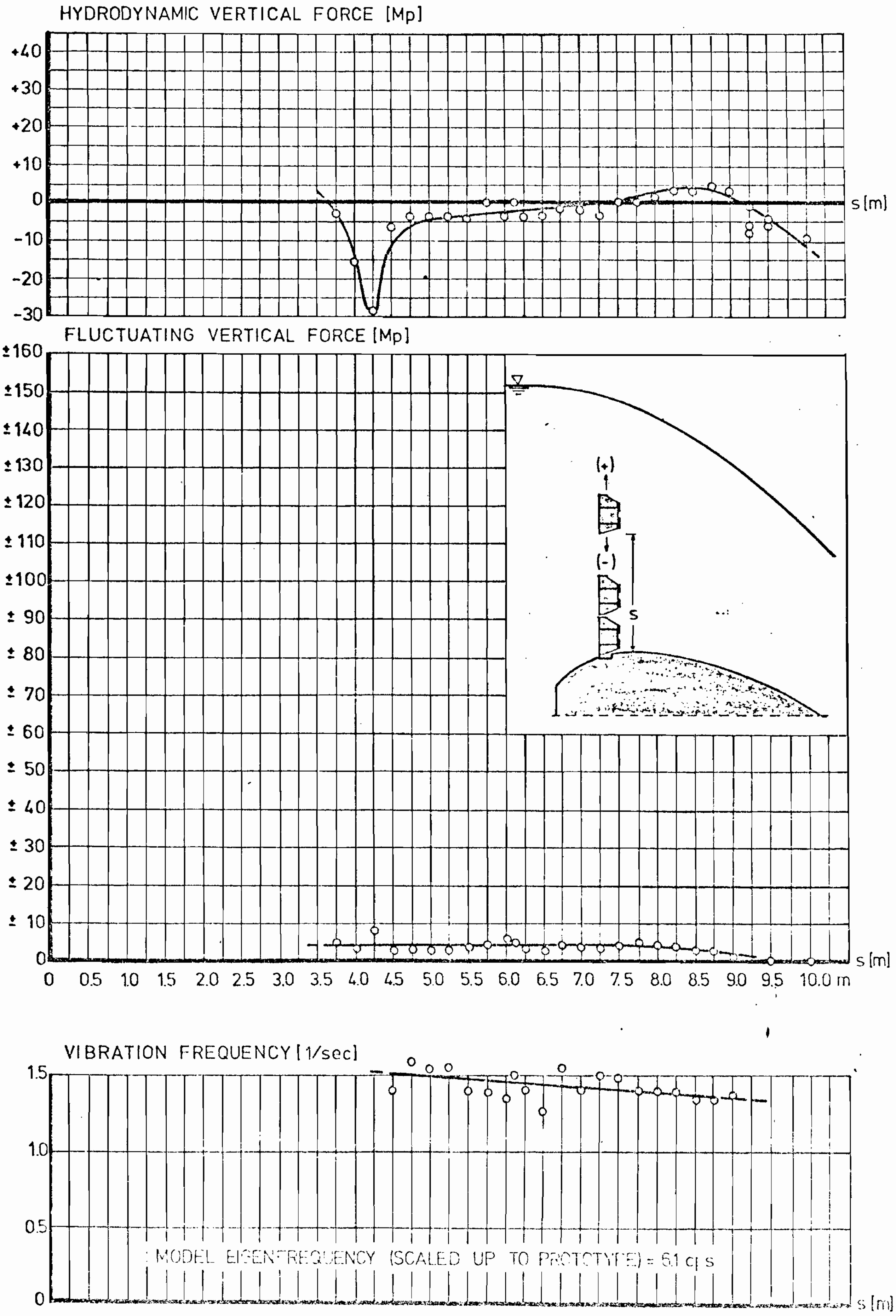

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s [m]
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0 m
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 6.1 c/s
s [m]

FIG.10

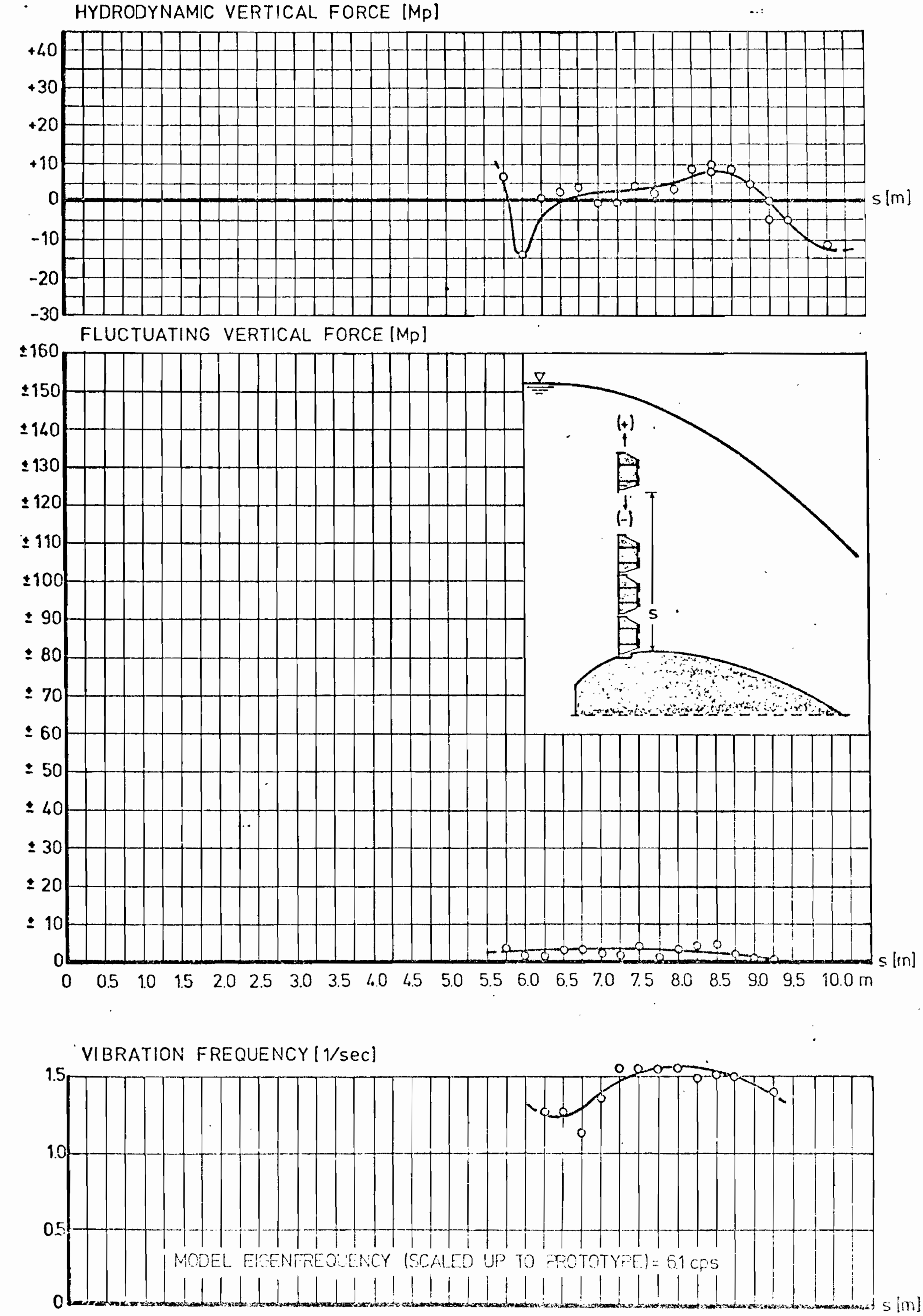

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 6.1 cps
s [m]

FIG.11

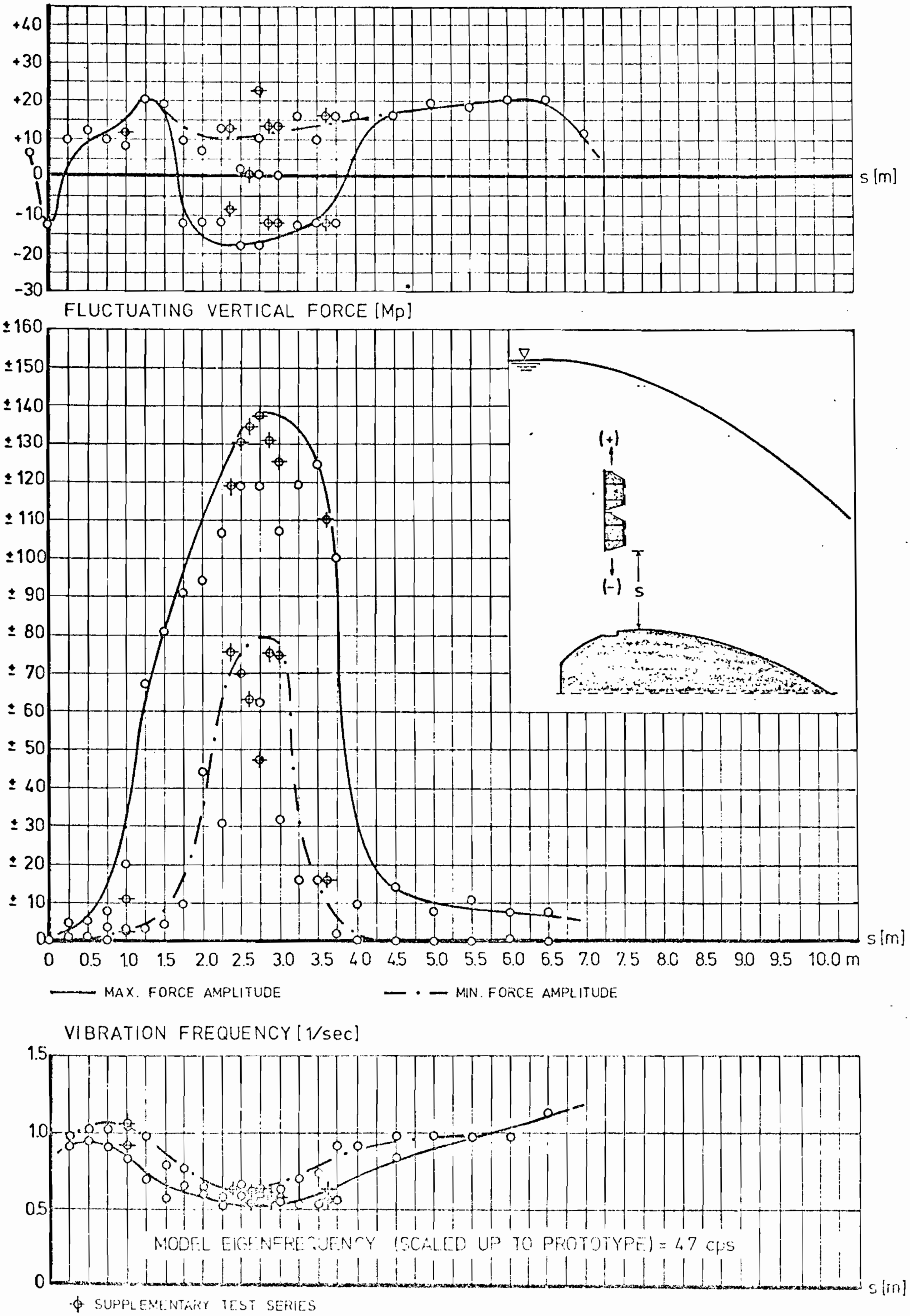

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
± 160
± 150
± 140
± 130
± 120
± 110
± 100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
MAX. FORCE AMPLITUDE
MIN. FORCE AMPLITUDE
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 47 cps
s [m]
SUPPLEMENTARY TEST SERIES

FIG. 12

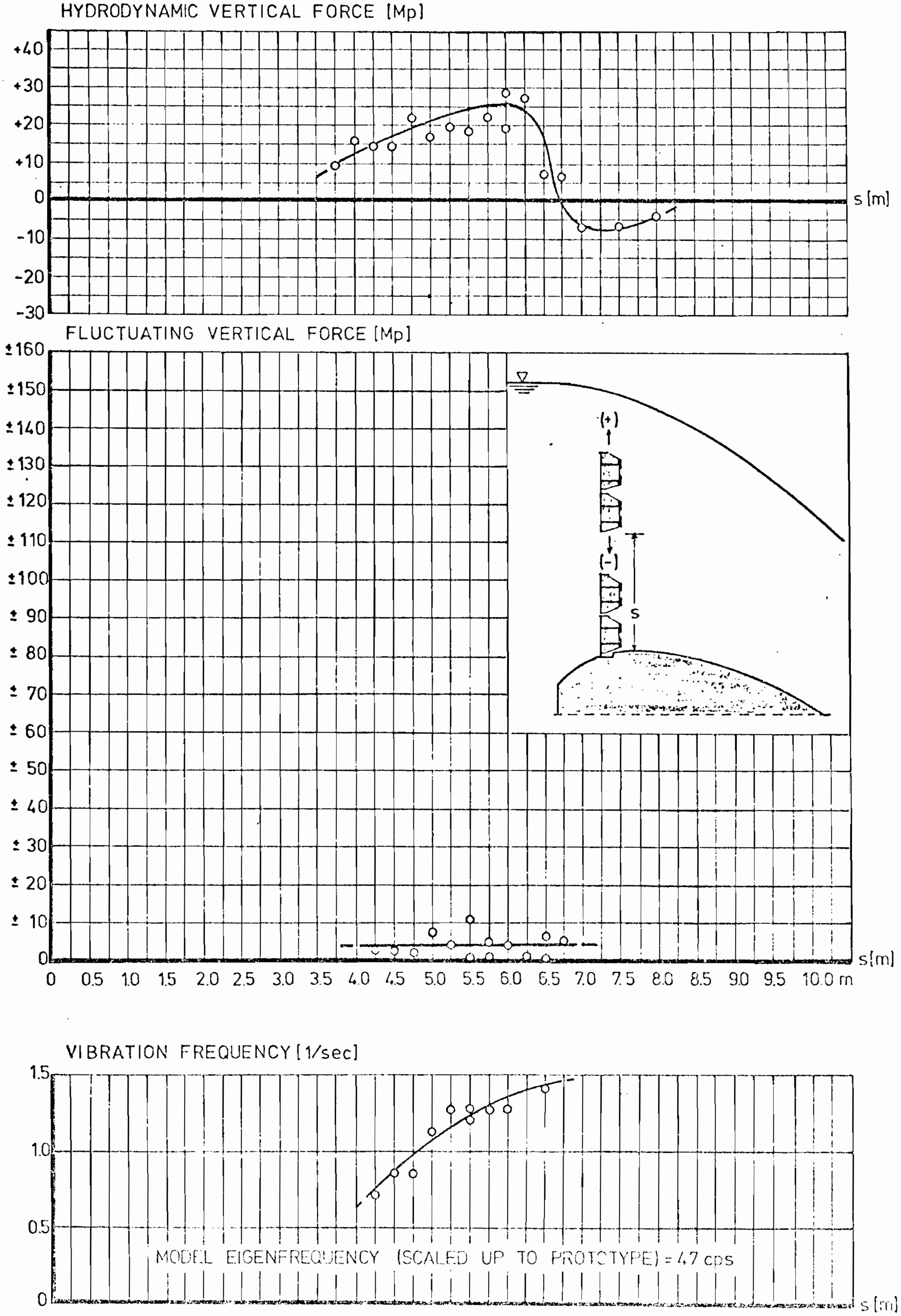

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s[m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 4.7 cps
s [m]

FIG. 13

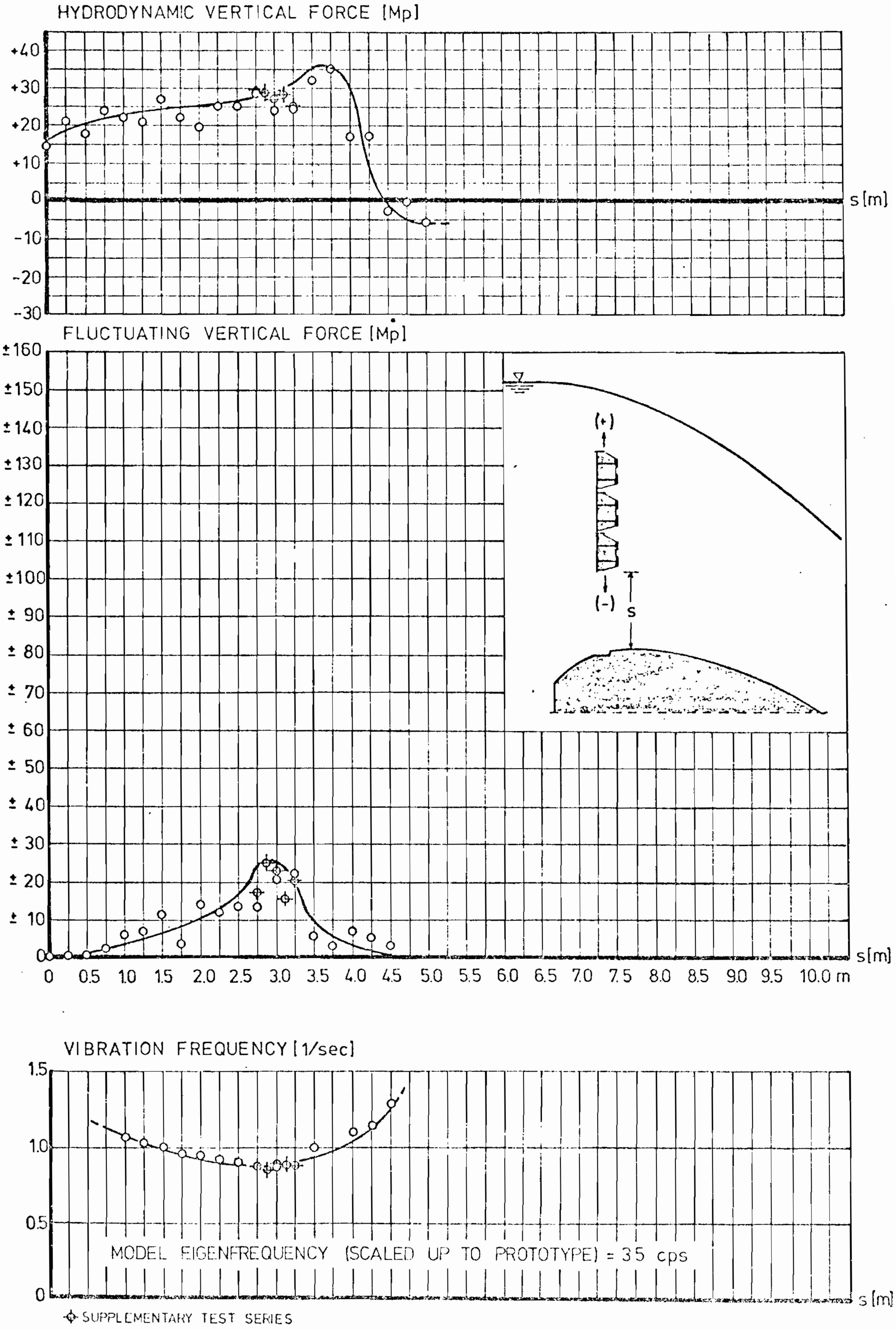

HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
VIBRATION FREQUENCY [1/sec]
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 35 cps
s [m]
SUPPLEMENTARY TEST SERIES

FIG.14

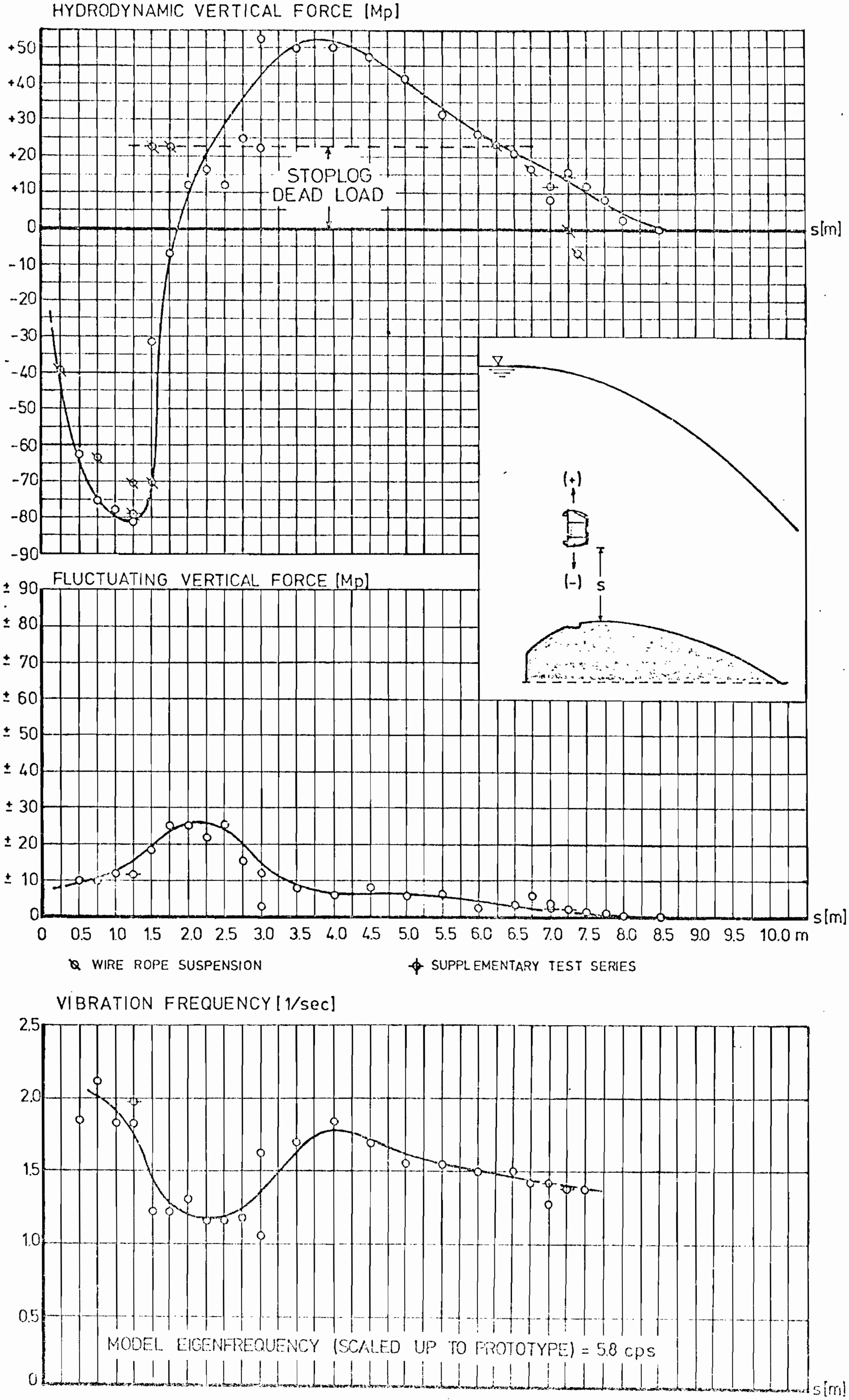
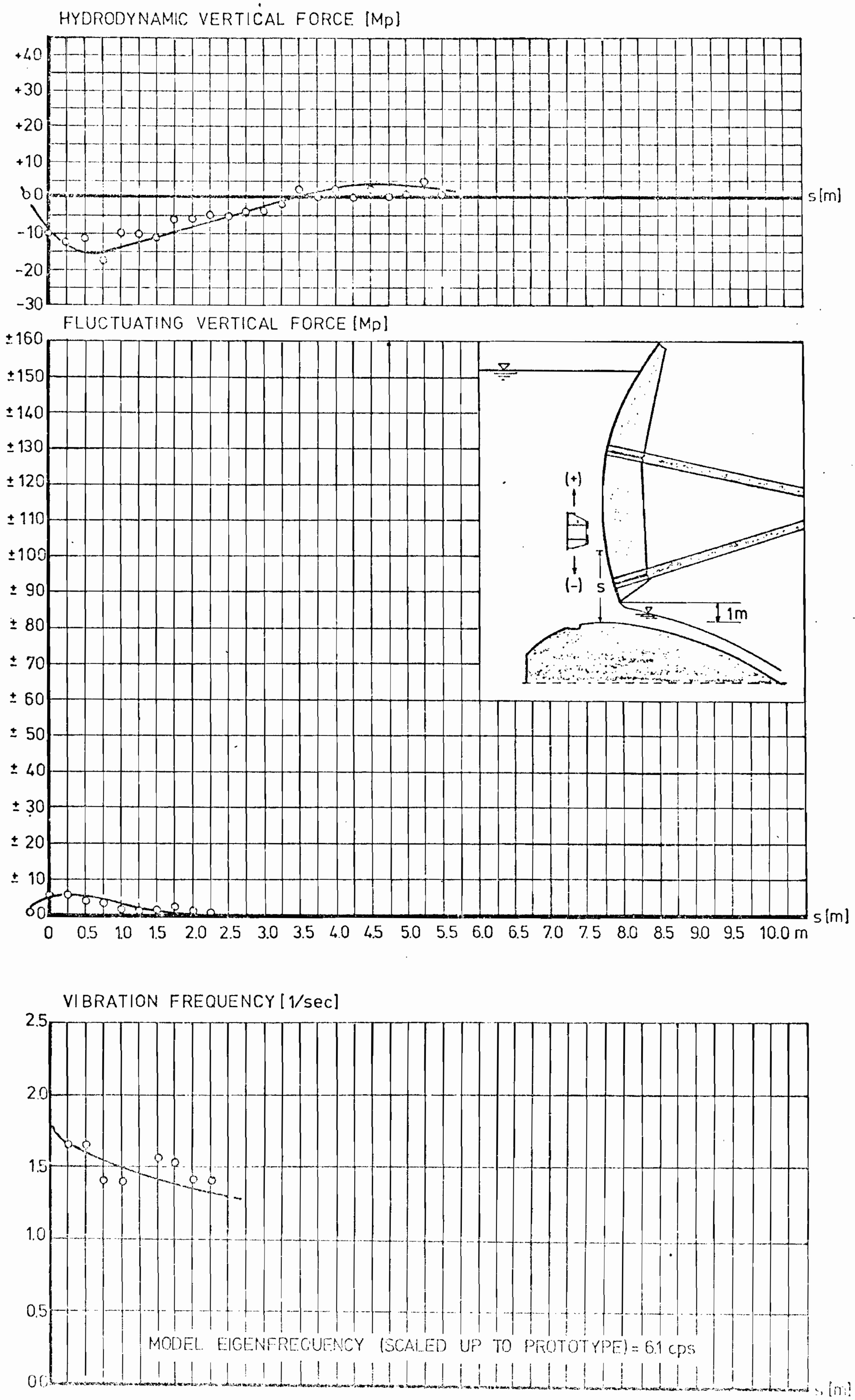
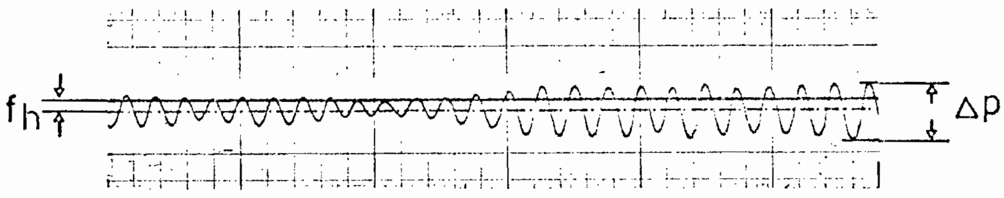

HYDRODYNAMIC VERTICAL FORCE [Mp]
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
STOPLOG
DEAD LOAD
s[m]
(+)
(-)
s
FLUCTUATING VERTICAL FORCE [Mp]
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
s[m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
WIRE ROPE SUSPENSION
SUPPLEMENTARY TEST SERIES
VIBRATION FREQUENCY [1/sec]
2.5
2.0
1.5
1.0
0.5
0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 5.8 cps
s[m]

FIG. 15


HYDRODYNAMIC VERTICAL FORCE [Mp]
+40
+30
+20
+10
0
-10
-20
-30
s [m]
FLUCTUATING VERTICAL FORCE [Mp]
±160
±150
±140
±130
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
(+)
(-)
s
1m
s [m]
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 m
VIBRATION FREQUENCY [1/sec]
2.5
2.0
1.5
1.0
0.5
0.0
MODEL EIGENFREQUENCY (SCALED UP TO PROTOTYPE) = 6.1 cps
s [m]

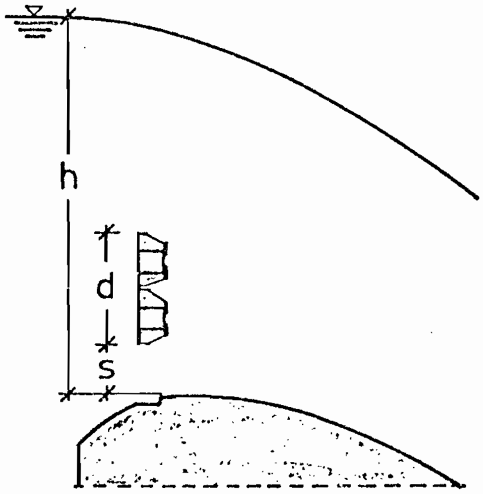
# EXCITATION COEFFICIENT $C_e$

FIG. 16



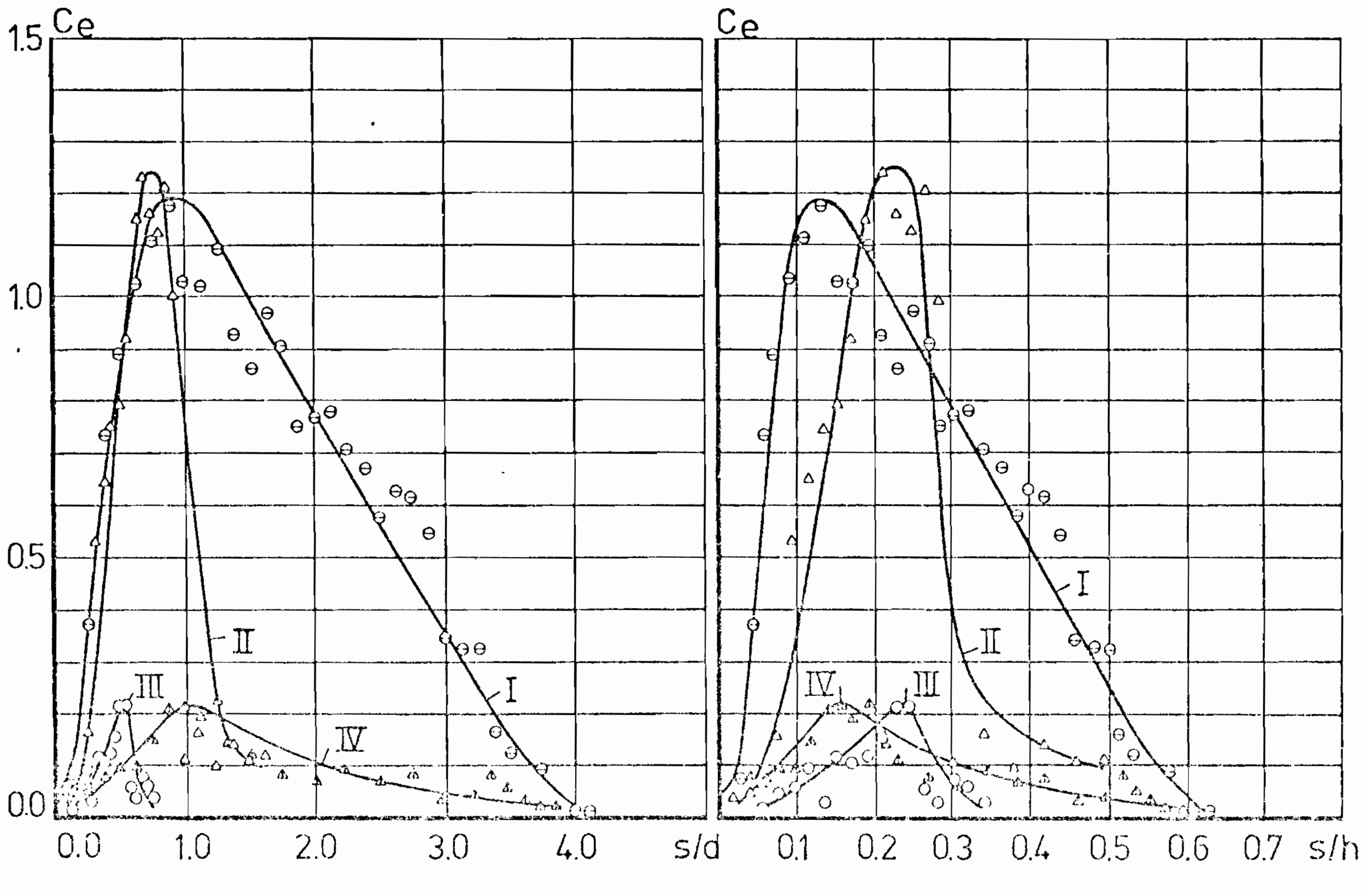

$$\frac{\Delta p}{2} = \text{FLUCTUATING VERTICAL FORCE}$$

$$f_h = \text{HYDRODYNAMIC VERTICAL FORCE}$$




$$C_e = \frac{\Delta p}{2\,\gamma\,F(h-s)}$$

I 1 Stoplog ⊖
II 2 Stoplogs coupled △
III 3 Stoplogs coupled ○
IV 1 Stoplog with facings ▲



Here seems to be a reasonable way for mitigating the vibration forces; it should be possible to get also a reduction of the mean hydrodynamic forces by suitable streamlining of the facings.

The last test series was performed with the radial gate at a partial opening rate of 1 m blocked as shown on fig. 15. As expected at such a low discharge vibration forces are extremely reduced and the fluctuating vertical force above 2.5 m stoplog position could no longer be noted.

In order to control the results with the rigid measurement system sometimes the stoplog was suspended by two wire ropes. So it could be checked that as long as hydrodynamic downpull was acting the forces were the same as measured with the rigid system (fig. 14).

In addition from the results on figs. 7, 11, 13 and 14, dimensionless presentations of them were established by plotting the excitation coefficient (see NAUDASCHER 1959)

$$C_e = \frac{\Delta p/2}{\gamma \cdot F \cdot (h - s)}$$

over the ratios s/d and s/h (fig. 16). It can be seen that the maximum of the fluctuating force always lies in the range

$$0.5 \leq s/d \leq 1$$

$$\text{or } 0.15 \leq s/h \leq 0.25$$

The exciting coefficient becomes more than 1 for cases I (1 stoplog) and II (2 stoplogs coupled); a reduction of the maximum exciting coefficient about $C_e \approx 0.2$ only occurs in cases III (3 stoplogs coupled) and IV (1 stoplog with facings).

## 4. Special observations:

4.1 As already mentioned before, the stoplog elements had been suspended by two circular rods of 2 mm diameter. Those suspending rods seemed to be the reason for a remarkable disturbance in the flow pattern to such an exent, that till to a certain stoplog depth the nappe was not strong enough to prevent air to entrain into the upper part of the wake. Additionally could be observed that there was a second possibility for air entrainment at the stoplog slots.

In order to get relative safe results those difficulties had to be overcome. Therefore special formed level control elements were attached to the suspending rods as to be seen from fig. 5, the upper parts of the stoplog slots were closed.

At this place it must be said, that whenever this procedure was carried out, it could be observed a magnification of the excitation as well as an increase of the upward hydrodynamic vertical force. This had been discovered soon after the first runs; therefore, all test series were carried out with these level control elements because the relative thin ropes in the prototype shall prevent air entrainment in their wakes by itself.

4.2 Significant for most of the hydrodynamic vertical force-curves is the maximum downpull at small opening rates (i.e. the distance between stoplog being lowered and the sill, respectively upper parts of the stoplog elements placed on the sill).

- 25 -

At those opening rates, especially in the test series according to figures 7 to 11, there was another phenomenon observed that had not been taken up into the diagrams: In accordance with the acting downpull there was noticed a steady vibration with characteristics difficult to be read from the oscillograms. As the peak to peak values of the amplitudes were very small and differed to a certain extent, frequencies could only be estimated approximately. In this way comparatively high frequencies were found

for test series according to fig. 8   18 cps. and

for test series according to fig. 9   8 cps.

Similar vibrations could also be recognized in the test series according to figs. 7, 10 and 11 but here it was not possible to count out the frequencies.

4.3 Test series performed with wire rope suspended stoplogs generally showed fluctuating vertical forces many times more those obtained from rod suspended stoplogs. The test series carried out in this way always ended with the stoplogs jumped out of the slots. The only exception to that rule was the modified stoplog after figs. 6 and 14. This matter of fact can be traced back to the more favourable working surface of the hydrodynamic vertical force as well as to the more downstream located separation zone.

4.4 The vibration process in the test series with two coupled stoplogs by far looked most dangerous. Here, the nappe also showed a strong fluctuating pattern resulting in a hard impact near the crest of the weir. This time it must be feared that in the prototype not only (the steel structures and) the suspension of the stoplogs but also the concrete of the weir could be damaged. Even though the maximum fluctuating vertical force in this case turned out to be a little less than that for only one stoplog, the above mentioned effect also is demonstrated by the maximum excitation coefficient $C_e \approx 1.25$ (see fig. 16).

## 5. A Remark on Scale Effects

As already mentioned in chapter 2, an existing model had to be used with the scale 1 to 50 according to the water supply.

For the problems to be studied here, 4 model laws have to be taken into consideration:

1. FROUDE's law

   Concerning gravitation and inertia forces

2. REYNOLDS' law

   Concerning inertia and viscosity (friction)

3. CAUCHY's law

   Concerning inertia and elasticity

4. WEBERS' law

   Concerning inertia and surface tensions

Before FROUDE's law had been used for scaling up to prototype, it must be shown that the other laws are of considerable less influence on forces and fluctuations than the law of FROUDE.

The influence of REYNOLDS'number by friction effects is negligible because wall resistance is small compared with the other forces. Also from the points of separation, no difficulties occur because they are fixed by the ends of the skinplate; exceptions only could be expected by some special forms of facings.

But there exists another scale effect by REYNOLDS' number in connection with the STROUHAL number:

$S = f \cdot d/v$

$f$ = frequency of the KARMAN wakes in the separation zone behind the stoplog

$d$ = height of stoplog structure

$v$ = stream velocity

For rigid circular cylinders, it has been shown that the STROUHAL number becomes constant for REYNOLDS' numbers higher than $R_e = 2\,000$ [3]. Here the REYNOLDS' numbers are, with $v = 5$ m/s approximately for the prototype and $\nu = 10^{-6}\ m^2/s$

$$\text{Prototype:} \qquad R_e = \frac{d \cdot v}{\nu} = \frac{2.0 \cdot 5}{10^{-6}} = 10^7$$

$$\text{Model:} \qquad R_e = \frac{0.04 \cdot 0.706}{10^{-6}} = 3 \cdot 10^4$$

Even for a structure different from a circular pile, the REYNOLDS' number of model and prototype are so high that constance of STROUHAL number can be expected.

In this case vibration frequencies can be scaled up after FROUDE's law.

Air entrainment, elasticity and damping effects are not included in this consideration. From CAUCHY's law the complete elasticity structure of the prototype has to be considered. It contains elasticities of the stoplogs and parts of it, of the ropes and the winching machinery. Additionally, the slackness of the bearings and rocking effects in the ropes are of influence. It is impossible to simulate all these components in a model after CAUCHY's law because suitable materials are not available. This is because the relations of density (masses) of the structure and the water must be the same in prototype and model.

However, it seems that vibration during overflow and underflow is more an effect of exciting vibration inside the nappe of water at the separation zone; therefore the elasticities of the structure can be neglected in first approximation. This has been pointed out especially by the physical model developed by NAUDASCHER [1, 2] ; in agreement with the tests of NAUDASCHER in the results presented here, no reasonable change of forces and amplitudes of fluctuations were found by changing the elasticity of the measuring system (chapter 2). For another hydroelastic system (two high head gates with short distance between each other) KRUMMET [4] found a good agreement between the measured forces and fluctuations in the prototype and in the model 1 to 10; he also neglected the elasticity of the model system.

In connection with CAUCHY's law, the elastical elongations in their coupling with the added masses of water also control the damping effects with viscous and turbulent friction. It is to be expected, however that the damping by turbulence mixing is predominant in the energy consumption of the vibrating nappe. Here scale effects are possible; it has been shown (chapter 3) that also friction damping from the rollers can have a considerable influence on the fluctuating forces. By air entrainment, the mixing process as well as the hydrodynamic loads are influenced too; because surface tension is the same in model and prototype, a similarity after WEBER's law cannot be established. It is difficult to separate these influences; the best way to get a better knowledge would be to use a family of models together with measurements in prototype. This, however, only can be a proposal of basic research and cannot be carried out inside the possibilities of this special investigation.

So it cannot be excluded that some scale effects are to be expected for the results presented in the study.

From the predominance of the selfexciting vibration of the water masses in the wake of the beams together with damping by turbulence mixing, however, it can be stated as sure that the order of magnitude, both of the forces and the amplitudes of fluctuations, will be similar in prototype and model for the different systems investigated.

For practical application, it seems not to be advisable here to adjust the structure against these strong forces and fluctuations; it should be better to seek for a solution where they can be avoided completely.

## 6. References

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Braunschweig, 15-11-1971